The First Observation of Circumstellar Nebula of VI Cyg 12 *

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(Received 18 December 2002)

An optical spectroscopic observation was made towards the circumstellar nebula of the supergiant VI Cyg 12, for the first time to the best of our knowledge. Several emission lines appear in the spectrum. Based on the spectra of the star and its circumstellar matter, as well as the IRAS and NVSS data, we conclude that VI Cyg 12 has an expanding shell with an expansion velocity 3100 km s^{-1} due to strong stellar wind. It is an older star that possibly evolved from a very massive O-type star. The stellar wind and mass loss may take an important part in the evolution of this star.

PACS: 95. 75. Fg, 97. 10. Me, 97. 20. Pm

High-mass supergiants are candidates of the progenitors of type Ⅱ supernovae, and one of the prime sources of metal production. Therefore, it is significant to study such a kind of stars and their interaction with surroundings.

VI Cyg 12 (Cygnus OB2 No. 12) was firstly discussed by Munch and Morgan in 1953.[1] It is the only late B star (B5Iab) known in the association, which is dominated by O-type stars. It is not a bright star in visual band (11.4 mag), but has very large reddening and extinction (Av $\sim$ 10 mag). Using the distance of the Cygnus OB2 association (2 kpc) Humphreys[2] can derive $M_v = -9.9$ mag and $M_{\rm bol} = -10.9$ mag, making one of the brightest known stars in the Galaxy.

Although VI Cyg 12 has been observed by many astronomers, no one has made spectroscopic observations to its circumstellar nebula. In order to understand the interaction between the supergiant and its surroundings, an optical spectroscopic observation was made by using 2.16 m telescope (with BEFOSC) of NAOC in Xinglong station on August 28 2001. The slit width of grating in BEFOSC is 3″. The signal-to-noise ratio in the spectra is more than 100. Calibration of flux has been carried out by observing the standard star HR 7950 in the same time span.

Figures 1(a) and 1(b) show the reduced spectra of the star and its circumstellar Nebula, respectively. This star is very difficult to observe in the blue spectral region due to very strong reddening. What we obtained in blue part ($<$ 5000 Å) is a flat and featureless spectra. Thus we only present the part of spectra between 5000 and 7000 Å.

Several emission lines are shown in the spectrum of the circumstellar nebula. Besides the relatively weaker H_α and possible N Ⅱ at 6583 and 6554 Å, there are several stronger O I emission lines, which have initially been identified as the atmospheric lines of the earth. We could not subtract them from the spectrum due to the fact what we observed is an extended source and is not a point source. The background is a mixture of the sky, the nebula and slightly scattered star light. Although most probably the O I emission lines are from our atmosphere, there is still a possibility that the lines are partially originated from the star or its surrounding based on the fact that the O I line (8446 Å) towards this star has been observed by using a high resolution Fabry–Perot spectrophotometer.[3] The appearance of H_α and N Ⅱ emission lines is a manifestation of an ionized zone.

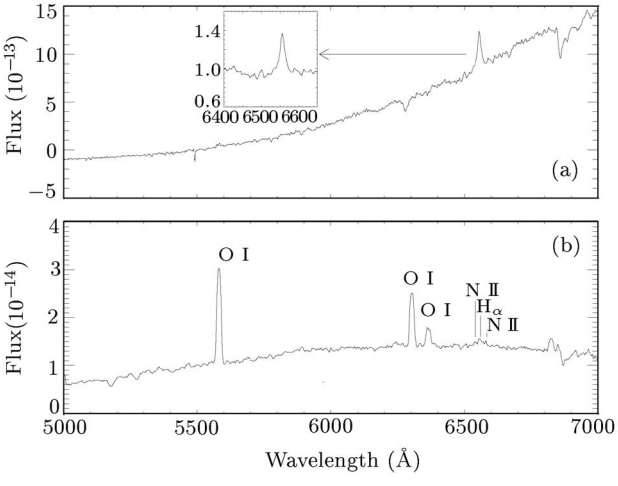


Fig. 1. Optical spectra of (a) VI Cyg 12 and (b) its circumstellar nebula.

A strong H_α emission line appears in the spectrum of the star. There are several distinct absorption lines of atmosphere of the earth. In Refs. [4,5], an absorption feature appeared at λ6532, which should not be present in the spectrum of a late B star. Thus it was interpreted as the H_α absorption due to an expanding shell, the implied expansion velocity is near 1400 $\rm kms^{-1}$. Such a shell must be extremely thin in order to appear to be a discrete line rather than a broad absorption trough. In our spectrum the H_α emission is stronger than that shown in the literature, and the equivalent width attains to 6.1 Å. It is obvious that the spectrum of VI Cyg 12 is in variation. From the enlarged normalized spectrum around H_α [see the insert in Fig. 1(a)], we can see a broad P cygni profile in

* Supported by the National Natural Science Foundation of China under Grant No 19935030.
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the blue part of H_α, which is different from Souza and Bromage's observation. The broad absorption implies a thick expanding shell around the star. The expansion velocity can be derived to be about 3100 kms^{-1}, over twice that of Souza. The reason for the large difference between the two spectra could be: (a) Something special happened in this star during the past 30 years, and caused the density of expanding shell changed suddenly. (b) The accuracy of Souza's observation was not high enough due to the relatively worse spectrometer.

It is not difficult to explain the phenomenon. The huge luminosity of this star certainly implies a strong stellar wind along with an extended atmosphere and mass loss. The variation of H_α emission line is just due to a changing density in the wind that is unstable.

Since it has a very large extinction towards VI Cyg 12, the expanding shell must consist of plenty of dust. The far infrared luminosity and temperature of the dust shell can be derived based on the IRAS data. Considering the distance of Cyg OB2 association (2 kpc), and the IRAS fluxes at 12, 25, 60 and 100 μm are 6.23, 2.21, 12.56 and 131.10 Jy respectively (upper limit at 100 μm), the far infrared luminosity of the star VI Cyg 12 can be computed using the following equation:[6]

$$L_{\mathrm{IRAS}}/L_\odot = 3.76\times10^2[9.75F12/12^2 + 34.0F25/25^2 + 37.5F60/60^2 + 39.67F100/100^2].$$

Thus the far infrared luminosity (upper limit) can be obtained to be 449 $L_\odot$. The IRAS colours suggest the presence of both cold dust ($\sim$ 80 K) and warm dust($\sim$ 900 K) around this star.

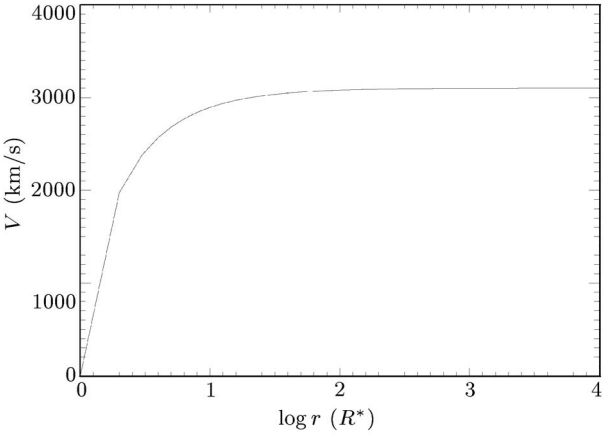


Fig. 2. Distribution of velocity of stellar wind from VI Cyg 12.

On the basis of the spectral type and the bolometric luminosity of VI Cyg 12, we can derive its effective temperature (T_{eff}) and radius (R_*) as 13600 K and 250 $R_\odot$ respectively. The velocity law of the wind is described as follows,

$$v(r) = v_0 + (v_\infty - v_0)(1 - R_*/r)^\beta,$$

where v_0 is the initial velocity. The value of v_0 used here is zero. The maxima velocity of the stellar wind is about 3100 km s^{-1}, which can be considered to be an approximation of v_∞. The parameter β is 0.65 for Cyg OB2 association. Figure 2 shows the calculated distribution of velocity of the stellar wind around VI Cyg 12. No distinct evidence appears in our spectrum to confirm this calculation due to the low resolution of the spectrum. We expect that in the future high resolution spectroscopic observations, one can find evidence of the stellar wind moving with different velocities, in agreement with what we predict in Fig. 2, at different distances away from the star.

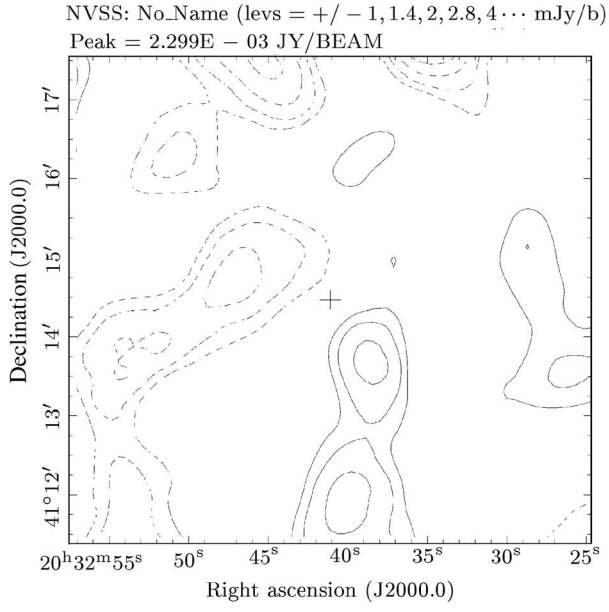


Fig. 3. Contour of VLA NVSS observation. The central cross marks the position of VI Cyg 12.

We also investigate the radio continuum structure of NVSS at 1.4 GHz (Fig. 3). It is clear that no radio continuum emission appears near VI Cyg 12. Therefore, we can conclude that no H II region exists around this star although there is weaker ionized emission line in the optical spectrum. The weaker forbidden lines could originate from the extended stellar atmosphere due to the strong stellar wind. Thus, VI Cyg 12 is not a young star, but an evolved star. The progenitor of the supergiant could be a very massive O-type star. Stellar wind and mass loss may have played a significant role in the evolution of this star.

We would like to thank Dr. K. Weis for her suggestion to make observations to this star.

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